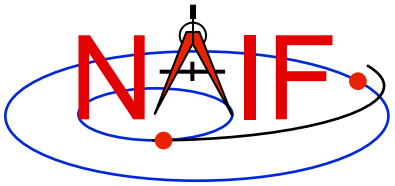


Frames Kernel
FK

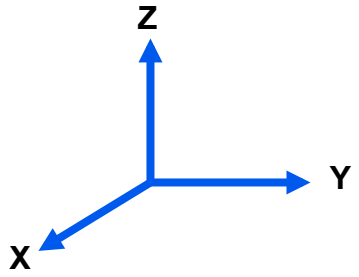
November 2014

Background

- First, reminders of what SPICE means by:
  - reference frame
  - coordinate system

What is a Reference Frame?

- Within SPICE, a reference frame is specified by three orthogonal axes



- It may be fixed in space (not rotating, not accelerating)
  - This is called an inertial frame
- It may be changing its orientation in space
  - This is called a non-inertial frame
- Every frame has a name assigned to it
  - You'll use these names as arguments in calling Toolkit APIs

What is a Coordinate System?

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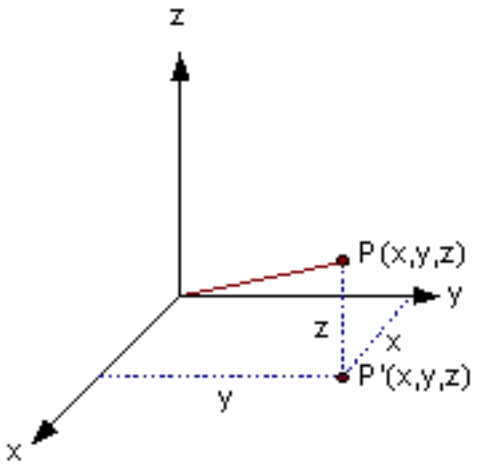
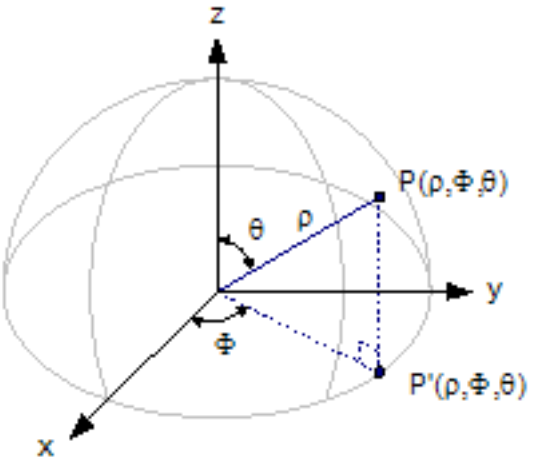
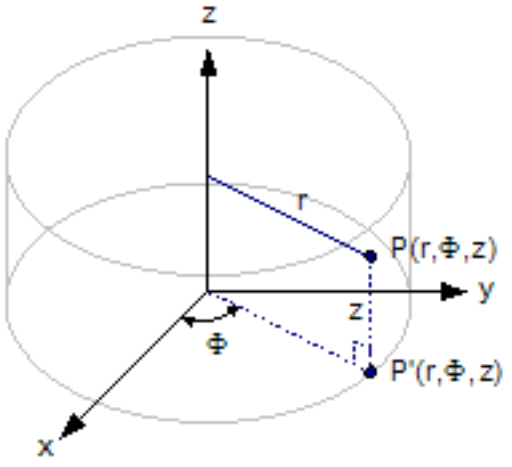
- **Within SPICE, a coordinate system is the method used to specify a vector within a reference frame. Examples:**



Rectangular



Spherical



Cylindrical

Introduction

What does the FRAMES subsystem do?

1. It establishes relationships between reference frames used in geometry computations – it "chains frames together" in a frame tree.

   and

2. It connects frames with the sources of their orientation specifications. In some cases those data are included in the Frames kernel.

Based on these relationships and the orientation source information, the frames subsystem allows SPICE software to compute rotations between neighboring frames in the frame tree, and to combine these rotations in the right order, thus providing an ability to compute the orientation of any frame in the tree with respect to any other frame in the tree, at any time.

Sample Frame Tree

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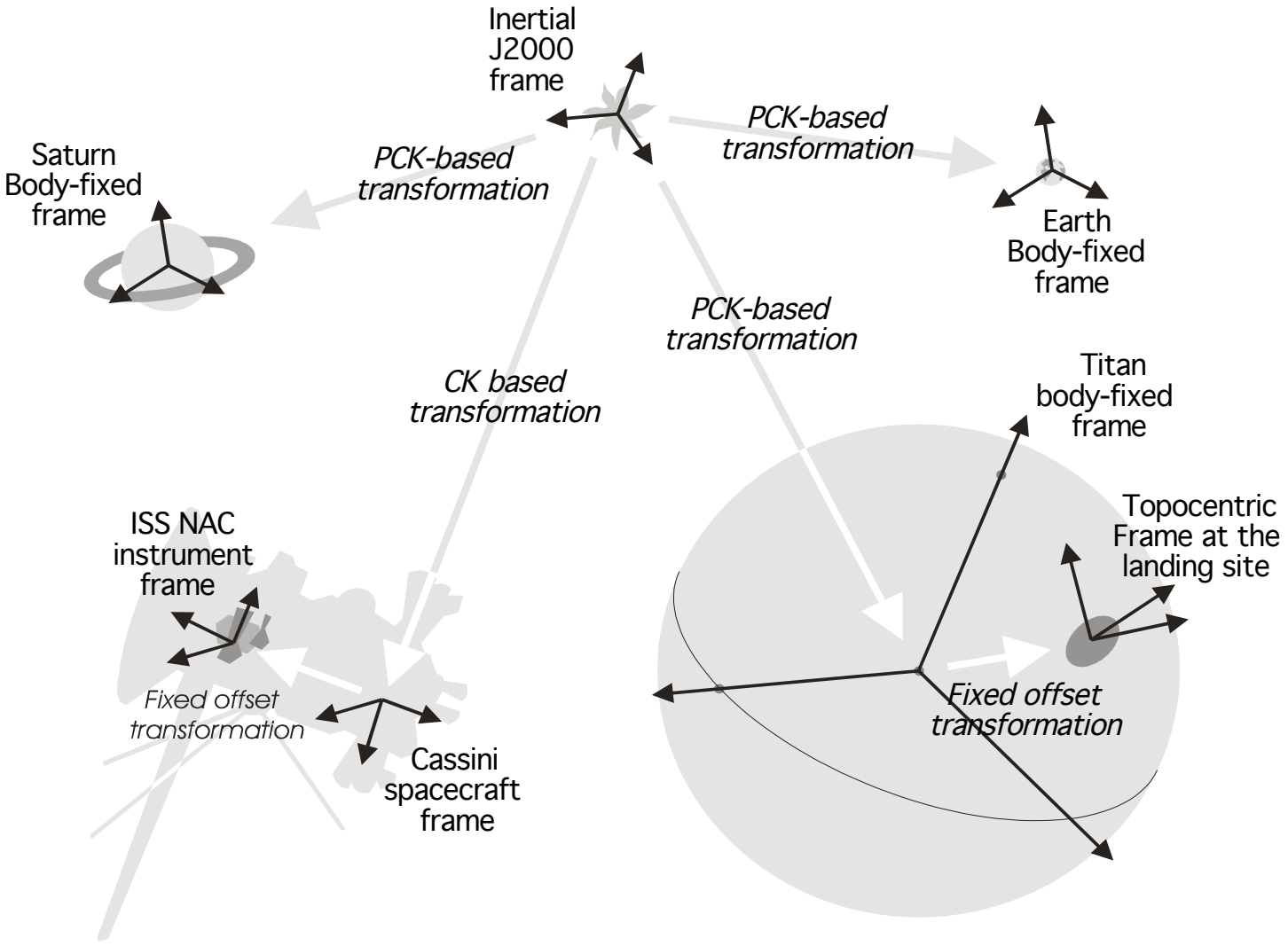

Frame Classes and Examples

Frame class	***Examples***
Inertial	• Earth Equator/Equinox of Epoch (J2000, …) • Planet Equator/Equinox of Epoch (MARSIAU, ...) • Ecliptic of Epoch (ECLIPJ2000, ...)
Body-fixed	• Solar system body IAU frames (IAU_MARS, IAU_SATURN, …) • High accuracy Earth frames (ITRF93, …) • High accuracy Moon frames (MOON_PA, MOON_ME)
CK-based	• Spacecraft (CASSINI_SC_BUS, …) • Moving parts of an instrument (MPL_RA_JOINT1, ...)
Fixed Offset	• Instrument mounting alignment (CASSINI_ISS_NAC, …) • Topocentric (DSS-14_TOPO, …)
Dynamic	• Geomagnetic • Geocentric Solar Equatorial • Planet true equator and equinox of date

Frame Class Specifications

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Frame class	*Frame Defined in:*	*Orientation data provided in:*
Inertial	Toolkit software	Toolkit software
Body-fixed	Toolkit software or FK	PCK
CK based	FK	CK
Fixed offset	FK	FK
Dynamic	FK	Toolkit software, or computed using FK, SPK, CK, and/or PCK

APIs Using the Frames Subsystem

Navigation and Ancillary Information Facility

SXFORM, PXFORM, and PXFRM2 — returns state or position transformation matrix

```
CALL SXFORM( 'FROM_FRAME_NAME', 'TO_FRAME_NAME', ET,           MAT6x6 )
CALL PXFORM( 'FROM_FRAME_NAME', 'TO_FRAME_NAME', ET,           MAT3X3 )
CALL PXFRM2( 'FROM_FRAME_NAME', 'TO_FRAME_NAME', ETFROM, ETTO, MAT3X3 )
```

SPKEZR
SPKPOS — returns state or position vector in specified frame

```
CALL SPKEZR( BOD, ET, 'FRAME_NAME', CORR, OBS, STATE,  LT )
CALL SPKPOS( BOD, ET, 'FRAME_NAME', CORR, OBS, POSITN, LT )
```

The above are FORTRAN examples, using SPICELIB modules.

The same interfaces exist for C, using CSPICE modules, and for IDL (Icy) and MATLAB (Mice).

Frame Names

- **Frame names are character strings used to identify frames to Toolkit APIs**

- **Examples of frame names:**
  - **J2000**
  - **IAU_MARS**
  - **DAWN_SPACECRAFT**
  - **MEX_OMEGA**
  - **DSS-14_TOPO**

Where to Find the Names of Frames?

- Refer to the “NAIF IDs” Tutorial for an introduction to reference frame names and IDs
- Refer to the FRAMES.REQ document for the list of NAIF “built in” (hard coded) inertial and body-fixed frames
- Refer to a project’s Frames Kernel (FK) file for a list of frames defined for the spacecraft, its subsystems and instruments
- Refer to an earth stations FK for a list of frames defined for the DSN and other stations
- Refer to the moon FKs for names and descriptions of the body-fixed frames defined for the moon

Frames Kernel File

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- Uses the SPICE text kernel standards
- Loaded using the FURNSH routine
- Usually contains comprehensive information about the defined frames in the comment section(s) of the file
- Contains frame definition information consisting of a set of keywords in the data sections of the file. Below are examples defining a CK-based frame and a fixed-offset frame.

CK-based Frame Example

```
FRAME_DAWN_SPACECRAFT  = -203000
FRAME_-203000_NAME     = 'DAWN_SPACECRAFT'
FRAME_-203000_CLASS    =  3
FRAME_-203000_CLASS_ID = -203000
FRAME_-203000_CENTER   = -203
CK_-203000_SCLK        = -203
CK_-203000_SPK         = -203
```

Fixed-offset Frame Example

```
FRAME_DAWN_FC1             =  -203110
FRAME_-203110_NAME         = 'DAWN_FC1'
FRAME_-203110_CLASS        =  4
FRAME_-203110_CLASS_ID     =  -203110
FRAME_-203110_CENTER       =  -203
TKFRAME_-203110_RELATIVE = 'DAWN_SPACECRAFT'
TKFRAME_-203110_SPEC       = 'ANGLES'
TKFRAME_-203110_UNITS      = 'DEGREES'
TKFRAME_-203110_ANGLES     = ( 0.0, 0.0, 0.0 )
TKFRAME_-203110_AXES       = ( 1,   2,   3   )
```

- These examples are discussed in detail in the next few slides

Frame Definition Details - 1

Navigation and Ancillary Information Facility

Frame definition for the DAWN spacecraft

```
FRAME_DAWN_SPACECRAFT   = -203000
FRAME_-203000_NAME      = 'DAWN_SPACECRAFT'
FRAME_-203000_CLASS     =  3
FRAME_-203000_CLASS_ID  = -203000
FRAME_-203000_CENTER    = -203
CK_-203000_SCLK         = -203
CK_-203000_SPK          = -203
```

Frame definition for the DAWN Framing Camera #1

```
FRAME_DAWN_FC1             =  -203110
FRAME_-203110_NAME         = 'DAWN_FC1'
FRAME_-203110_CLASS        =  4
FRAME_-203110_CLASS_ID     =  -203110
FRAME_-203110_CENTER       =  -203
TKFRAME_-203110_RELATIVE   = 'DAWN_SPACECRAFT'
TKFRAME_-203110_SPEC       = 'ANGLES'
TKFRAME_-203110_UNITS      = 'DEGREES'
TKFRAME_-203110_ANGLES     = ( 0.0, 0.0, 0.0 )
TKFRAME_-203110_AXES       = ( 1,   2,   3   )
```

- **The Frame ID, shown in red in the two examples above, is an integer number used by the SPICE system as a “handle” in buffering and retrieving various parameters associated with a frame. In an FK it “glues together” the keywords defining the frame.**

Frame Definition Details - 2

Navigation and Ancillary Information Facility

Frame definition for the DAWN spacecraft

```
FRAME_DAWN_SPACECRAFT  = -203000
FRAME_-203000_NAME     = 'DAWN_SPACECRAFT'
FRAME_-203000_CLASS    =  3
FRAME_-203000_CLASS_ID = -203000
FRAME_-203000_CENTER   = -203
CK_-203000_SCLK        = -203
CK_-203000_SPK         = -203
```

Frame definition for the DAWN Framing Camera #1

```
FRAME_DAWN_FC1            =  -203110
FRAME_-203110_NAME        = 'DAWN_FC1'
FRAME_-203110_CLASS       =  4
FRAME_-203110_CLASS_ID    =  -203110
FRAME_-203110_CENTER      =  -203
TKFRAME_-203110_RELATIVE  = 'DAWN_SPACECRAFT'
TKFRAME_-203110_SPEC      = 'ANGLES'
TKFRAME_-203110_UNITS     = 'DEGREES'
TKFRAME_-203110_ANGLES    = ( 0.0, 0.0, 0.0 )
TKFRAME_-203110_AXES      = ( 1,   2,   3   )
```

- These keywords

  `FRAME_<name>  = <id>`

  `FRAME_<id>_NAME = <name>`

establish the association between the name and the ID of the frame.

Frame Definition Details - 3

Navigation and Ancillary Information Facility

Frame definition for the DAWN spacecraft

```
FRAME_DAWN_SPACECRAFT   = -203000
FRAME_-203000_NAME      = 'DAWN_SPACECRAFT'
FRAME_-203000_CLASS     =  3
FRAME_-203000_CLASS_ID  = -203000
FRAME_-203000_CENTER    = -203
CK_-203000_SCLK         = -203
CK_-203000_SPK          = -203
```

Frame definition for the DAWN Framing Camera #1

```
FRAME_DAWN_FC1            =  -203110
FRAME_-203110_NAME        = 'DAWN_FC1'
FRAME_-203110_CLASS       =  4
FRAME_-203110_CLASS_ID    =  -203110
FRAME_-203110_CENTER      =  -203
TKFRAME_-203110_RELATIVE  = 'DAWN_SPACECRAFT'
TKFRAME_-203110_SPEC      = 'ANGLES'
TKFRAME_-203110_UNITS     = 'DEGREES'
TKFRAME_-203110_ANGLES    = ( 0.0, 0.0, 0.0 )
TKFRAME_-203110_AXES      = ( 1,   2,   3   )
```

- The FRAME…CLASS keyword specifies the method by which the frame is related to its base frame
- This keyword is set to:
  - 2, for PCK-based frames
  - 3, for CK-based frames
  - 4, for fixed-offset frames
  - 5, for dynamic frames

Frame Definition Details - 4

Navigation and Ancillary Information Facility

Frame definition for the DAWN spacecraft

```
FRAME_DAWN_SPACECRAFT   = -203000
FRAME_-203000_NAME      = 'DAWN_SPACECRAFT'
FRAME_-203000_CLASS     =  3
FRAME_-203000_CLASS_ID  = -203000
FRAME_-203000_CENTER    = -203
CK_-203000_SCLK         = -203
CK_-203000_SPK          = -203
```

Frame definition for the DAWN Framing Camera #1

```
FRAME_DAWN_FC1             =  -203110
FRAME_-203110_NAME         = 'DAWN_FC1'
FRAME_-203110_CLASS        =  4
FRAME_-203110_CLASS_ID     =  -203110
FRAME_-203110_CENTER       =  -203
TKFRAME_-203110_RELATIVE   = 'DAWN_SPACECRAFT'
TKFRAME_-203110_SPEC       = 'ANGLES'
TKFRAME_-203110_UNITS      = 'DEGREES'
TKFRAME_-203110_ANGLES     = ( 0.0, 0.0, 0.0 )
TKFRAME_-203110_AXES       = ( 1,   2,   3   )
```

- **The FRAME…CLASS_ID is the number that connects a frame with the orientation data for it.**
  - **For body-fixed frames the CLASS_ID is the ID of the natural body. It is used as input to PCK routines called by the Frame subsystem to compute orientation of the frame.**
    - » **The Frame ID and CLASS_ID are not the same for the body-fixed frames defined in the Toolkit but they can be the same for frames defined in FK files.**
  - **For CK-based frames the CLASS_ID is the CK structure ID. It is used as input to CK routines called by the Frame subsystem to compute orientation of the frame.**
    - » **Usually the CLASS_ID of a CK-based frame is the same as the frame ID, but this is not required.**
  - **For fixed offset and dynamic frames the CLASS_ID is the ID that is used to retrieve the frame definition keywords.**
    - » **The CLASS_ID of a fixed offset or dynamic frame is the same as the frame ID.**

Frame Definition Details - 5

Navigation and Ancillary Information Facility

Frame definition for the DAWN spacecraft

```
FRAME_DAWN_SPACECRAFT   = -203000
FRAME_-203000_NAME      = 'DAWN_SPACECRAFT'
FRAME_-203000_CLASS     =  3
FRAME_-203000_CLASS_ID  = -203000
FRAME_-203000_CENTER    = -203
CK_-203000_SCLK         = -203
CK_-203000_SPK          = -203
```

Frame definition for the DAWN Framing Camera #1

```
FRAME_DAWN_FC1             =  -203110
FRAME_-203110_NAME         = 'DAWN_FC1'
FRAME_-203110_CLASS        =  4
FRAME_-203110_CLASS_ID     =  -203110
FRAME_-203110_CENTER       =  -203
TKFRAME_-203110_RELATIVE   = 'DAWN_SPACECRAFT'
TKFRAME_-203110_SPEC       = 'ANGLES'
TKFRAME_-203110_UNITS      = 'DEGREES'
TKFRAME_-203110_ANGLES     = ( 0.0, 0.0, 0.0 )
TKFRAME_-203110_AXES       = ( 1,   2,   3   )
```

- The FRAME…CENTER specifies the ephemeris object at which the frame origin is located
  - It is used ONLY to compute the light-time corrected orientation of the frame

Frame Definition Details - 6

Navigation and Ancillary Information Facility

Frame definition for the DAWN spacecraft

```
FRAME_DAWN_SPACECRAFT   = -203000
FRAME_-203000_NAME      = 'DAWN_SPACECRAFT'
FRAME_-203000_CLASS     =  3
FRAME_-203000_CLASS_ID  = -203000
FRAME_-203000_CENTER    = -203
CK_-203000_SCLK         = -203
CK_-203000_SPK          = -203
```

Frame definition for the DAWN Framing Camera #1

```
FRAME_DAWN_FC1             =  -203110
FRAME_-203110_NAME         = 'DAWN_FC1'
FRAME_-203110_CLASS        =  4
FRAME_-203110_CLASS_ID     =  -203110
FRAME_-203110_CENTER       =  -203
TKFRAME_-203110_RELATIVE = 'DAWN_SPACECRAFT'
TKFRAME_-203110_SPEC       = 'ANGLES'
TKFRAME_-203110_UNITS      = 'DEGREES'
TKFRAME_-203110_ANGLES     = ( 0.0, 0.0, 0.0 )
TKFRAME_-203110_AXES       = ( 1,   2,   3   )
```

- Additional frame definition keywords may be required depending on the frame class
  - For CK frames, CK…SCLK and CK…SPK keywords identify the spacecraft clock ID and physical object ID associated with the CK structure ID
  - For fixed-offset frames, TKFRAME_* keywords specify the base frame and the fixed orientation with respect to this frame
  - For dynamic frames, additional keywords depend on the dynamic frame family

CK-Based Frames "Must Know"

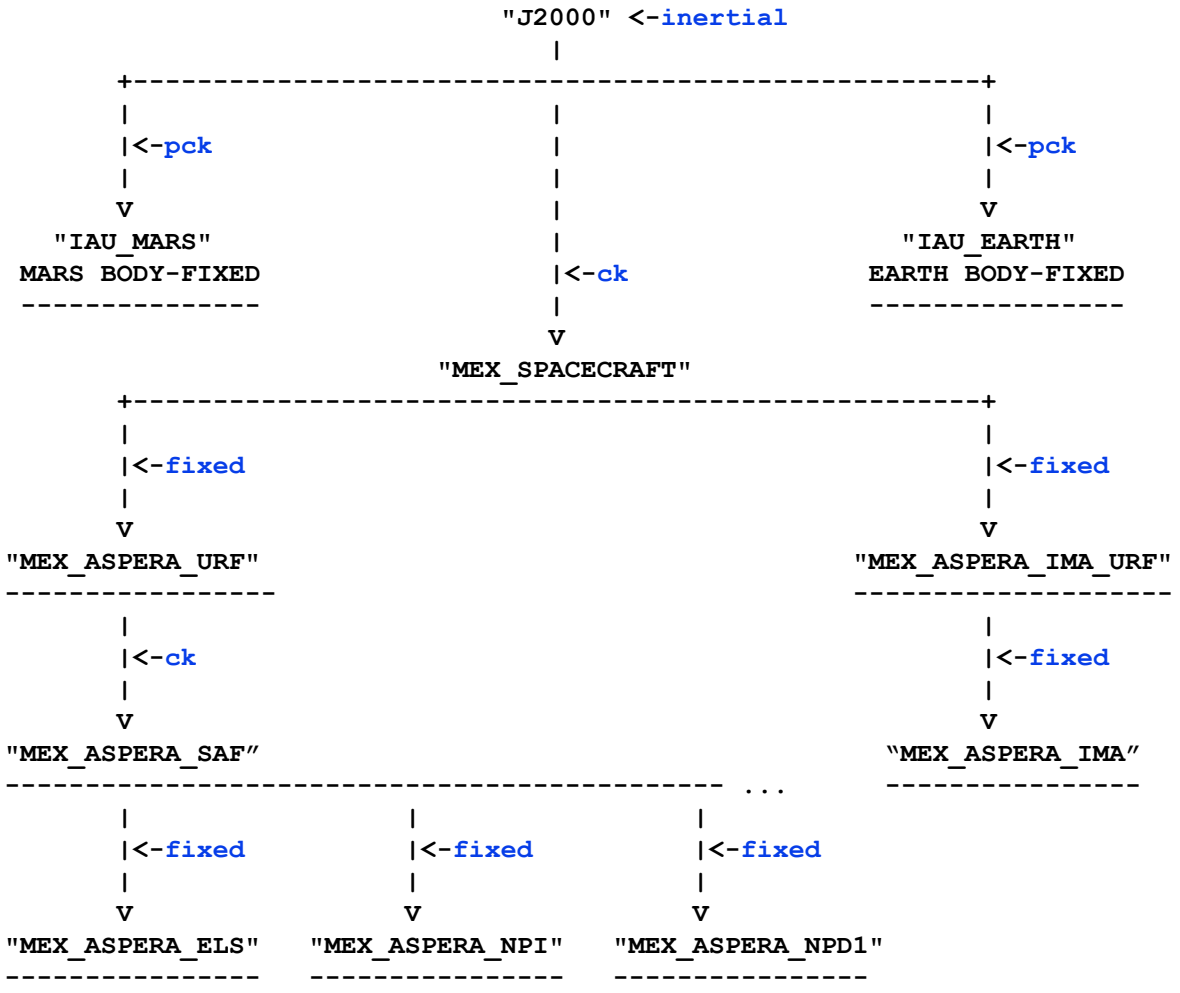
Navigation and Ancillary Information Facility

These are VERY IMPORTANT points you must understand!

- **The frames routines (SPKEZR, SPKPOS, SXFORM, PXFORM) all read CK files using tolerance = 0**
  - **For discrete CKs (Type 1) the orientation of a CK-based frame will be computed only if the time provided to a Frames routine exactly matches one of the times stored in the CK file; otherwise an error will be signaled.**
  - **For continuous CKs (Types 2 – 6) the orientation of a CK-based frame will be computed only if the time provided to a Frames routine falls within one of the interpolation intervals defined by the CK file; otherwise an error will be signaled.**
- **Using SPKEZR or SXFORM requires CKs that contain angular rate data**
  - **Since these routines return a state vector (6x1) or state transformation matrix (6x6), angular rate must be present in the CK in order to compute vectors and matrices; if angular rate is not present an error will be signaled.**
  - **SPKPOS and PXFORM, which return a position vector (3x1) and a position transformation matrix (3x3) respectively, can be used when angular rate data are NOT present in a CK.**
- **Ephemeris time input to Frames routines is converted to SCLK to access CKs**
  - **SCLK and LSK kernels must be loaded to support this conversion.**
  - **The SCLK ID is specified in one of the CK frame definition keywords; if not, it's assumed to be the Frame ID divided by a 1000.**

Frame Tree Example: ASPERA Instrument on Mars Express

Navigation and Ancillary Information Facility



Blue text indicates frame class

FK Utility Programs

- **The following FK and frames utility programs are included in the Toolkit**

FRMDIFF	samples orientation of a frame or compares orientation of two frames
CKBRIEF	summarizes coverage for one or more CK files
BRIEF	summarizes coverage for one or more binary PCK files

- **These additional FK and frames utility programs are provided on the NAIF Web site**

PINPOINT	creates SPK and topocentric frames FK files for fixed locations (ground stations, etc)
BINGO	converts FK files between UNIX and DOS text formats

Additional Information on FK

- For more information about FK and frames, look at the following documents
  - Frames Required Reading
  - Using Frames Tutorial
  - Dynamic Frames Tutorial
  - NAIF IDs Tutorial
  - Headers for the routines mentioned in this tutorial
  - Most Useful SPICELIB Routines
  - FRMDIFF User's Guide
  - Porting_kernels tutorial
- Related documents
  - CK Required Reading
  - PCK Required Reading
  - SPK Required Reading
  - Rotations Required Reading